eg. Cosmic ray muons are produced in the upper atmosphere, 80 km up, and move at 0.99c to Earth. They have a lifetime of 2.2×10^{-6}s.

a) what is the lifetime of muons in the frame of reference of the Earth?

$t=\gamma t_o$ t_o is proper time, events with no relative motion

t is relativistic time, with relative motion

$$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{(0.99c)^2}{c^2}}} = \frac{1}{\sqrt{1-0.9801}}$$

$$\gamma = 7.09$$

t = 7.09x2.2=15.598 16microseconds

a) what is the height of the atmosphere in the frame of reference of the muons?

$L=L_o/\gamma$ = 80/7.09=11.2835 = 11km

a) how long does it take for the muons to reach the Earth in i) Earth's frame ii)muon's frame

$t=d/v = 80km/(0.99x3.00x10^8 m/s)$

80000/(0.99x300000000)=0.0003 m

300μs

a) 11283.5/(0.99x300000000)=0.000038 m

38 μs

Twin's Paradox:

how can both clocks run slow?

One twin leaves in rocket at v, turns around and comes back.

Both observe the other's clock running slow but when you do the experiment, the travelling twin is younger than the stay at home twin.

What's the deal?

solution:

Simultaneity: events that are simultaneous (same time) in one frame are not in another frame:

$t'=\gamma\{t-[(vx)/c^2]\}$

so, the time on Earth gets altered when you shift from one space-time frame moving at v to another frame moving at -v.

Best observed in Minkowski space-time

diagrams.

When doing a Minkowski space-time transformation, the axis are altered by an angle, θ where $\theta=\tan^{-1}(v/c)$

Nothing moves faster than c, or even accelerates to c.

What about two spaceships moving at 0.6c towards each other?

Galileo $u' = u - v$ so $u' = 0.6c - (-0.6c) = 1.2c$

Einstein $u' = (u-v)/(1-uv/c^2)$

so $u' = (0.6c-(-0.6c))/(1-(0.6c)(-0.6c)/c^2)$

$u' = 1.2c/(1.36)$ $1.2/1.36=0.8824$

$u' = 0.88c$ in the frame of the other rocket.

eg. Cindy is going to Alpha Centauri , 4.5 light years away, at 0.99c.

a) what is gamma?
b) how long does the trip to the star take in
 i) Cindy's frame ii)Amy (stays on Earth)'s frame
c) What time is it on Earth in Cindy's frame before/after the turn around. (tricky)
d) When Cindy gets back, how much younger is she than Amy?
e) What distance was covered in Cindy's frame?

Homework - look over the exam style questions.

Q3, 4, 6 (8 is HL only)

https://www.youtube.com/watch?v=BFLUa0ciMjw